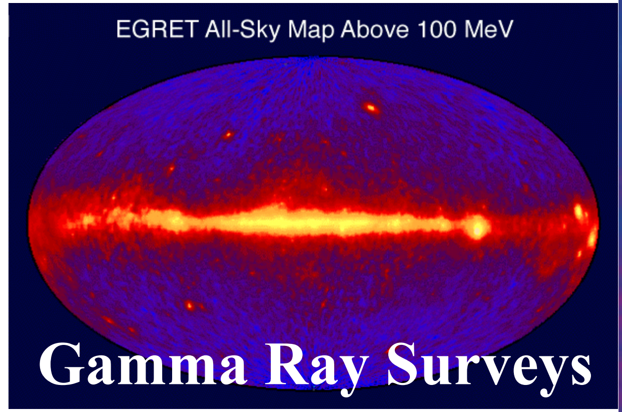
# Overview of SEU Research at GSFC

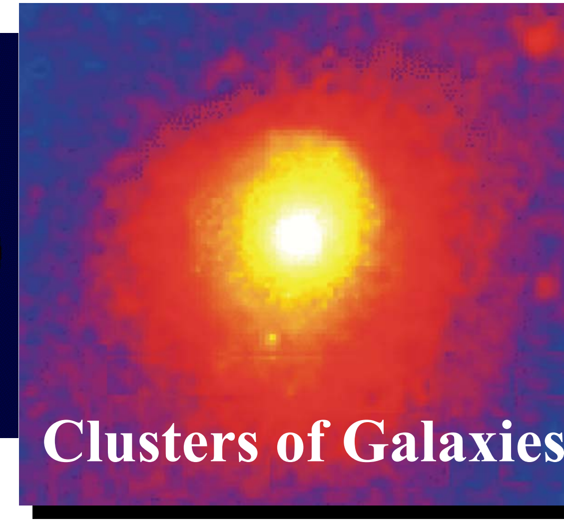
Nicholas White
Chief,
Laboratory for High Energy Astrophysics

# Laboratory for High Energy Astrophysics

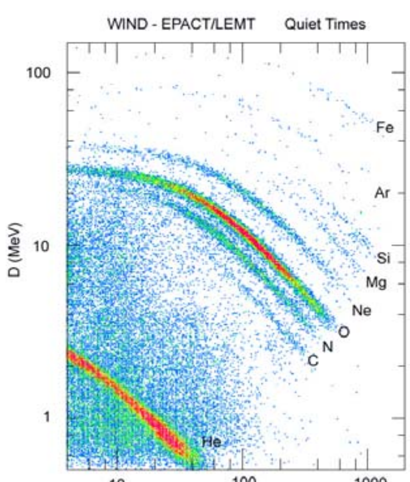
Supernova Remnants



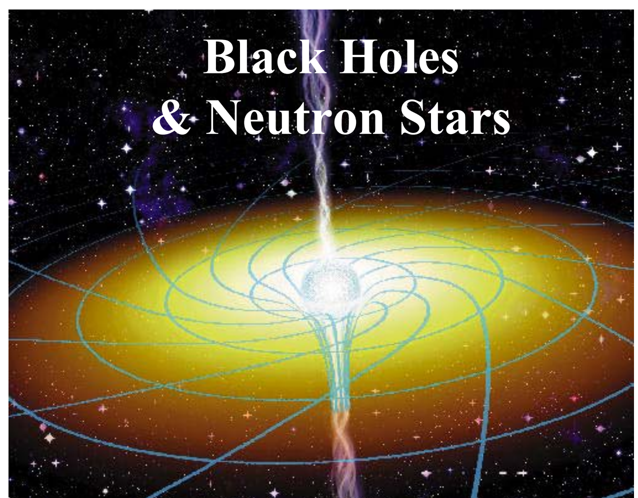

Gamma Ray Surveys



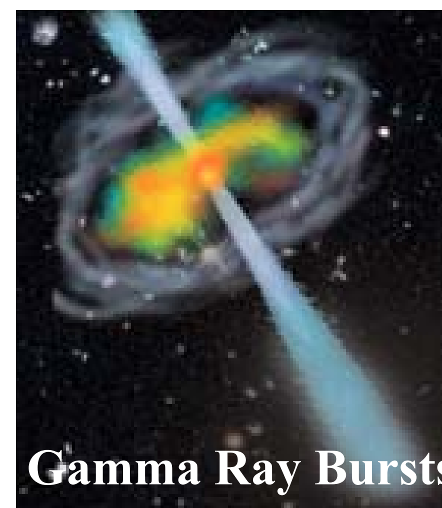
Clusters of Galaxies




Cosmic Rays



Black Holes
& Neutron Stars



Gamma Ray Bursts

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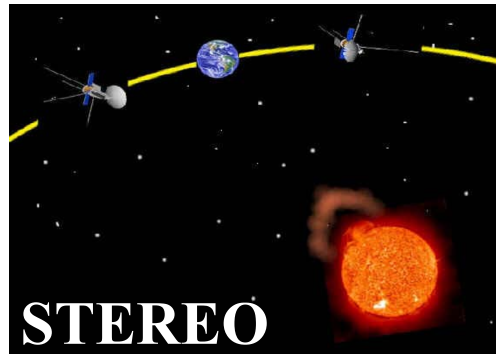
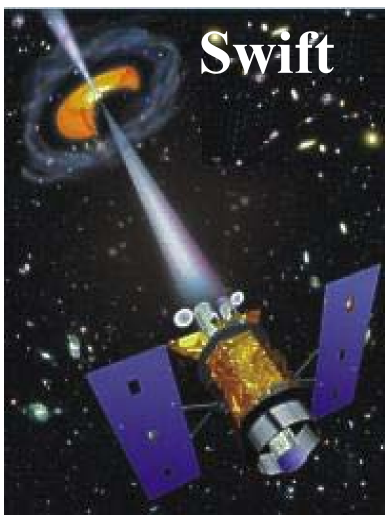
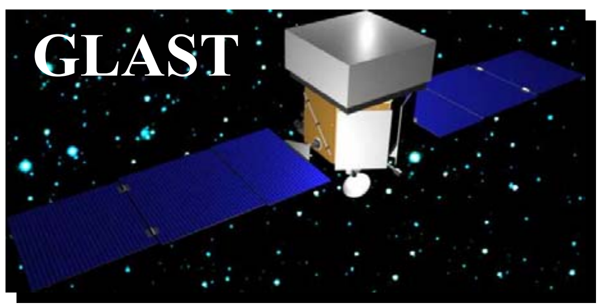
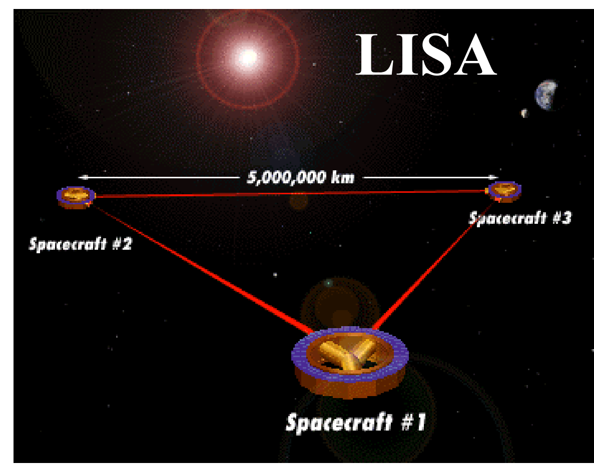
# Future LHEA Missions






LHEA
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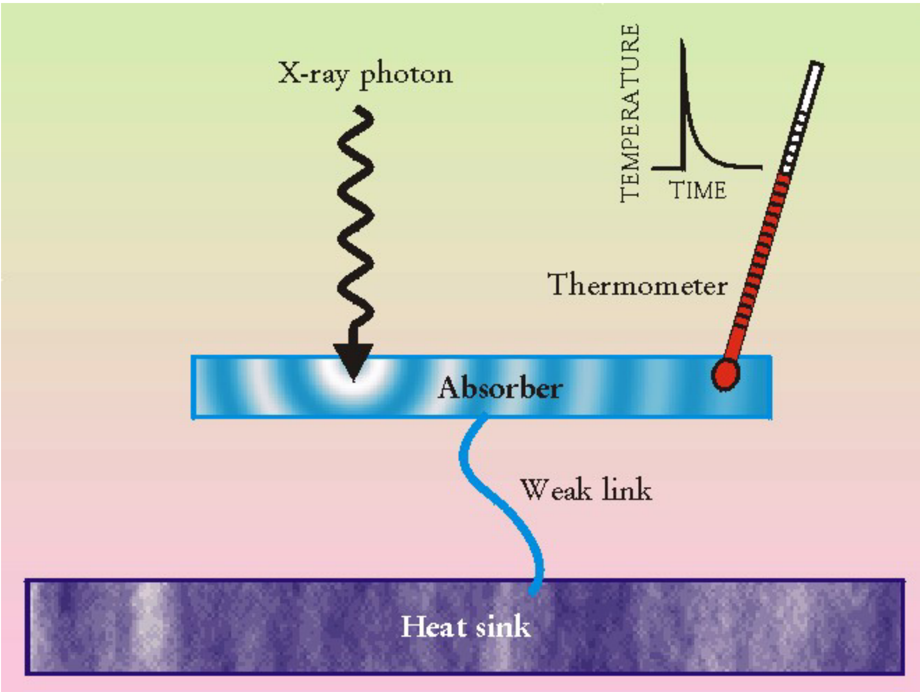
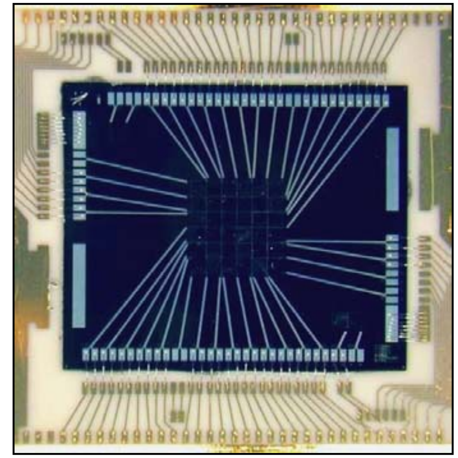
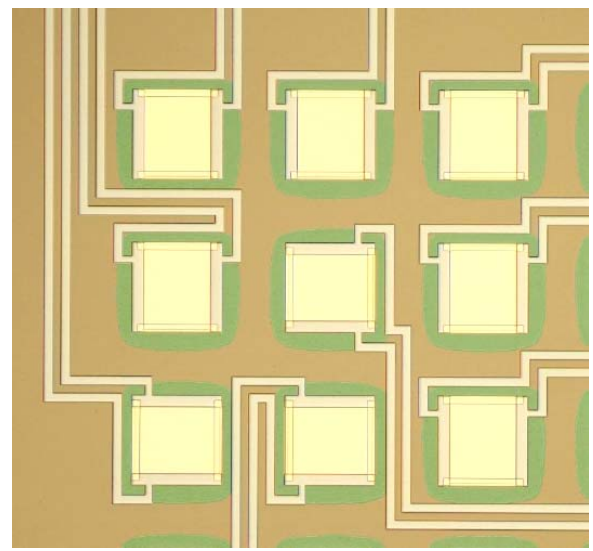
# X-ray Micro-calorimeter arrays




LHEA invented and has steadily supported the development of the x-ray microcalorimeter spectrometer towards flight on Astro-E2 and Constellation-X



Astro-E2 2-d array.



Portion of 5 x 5 Mo/Au TES array produced at GSFC. Pixel pitch is 250 microns.

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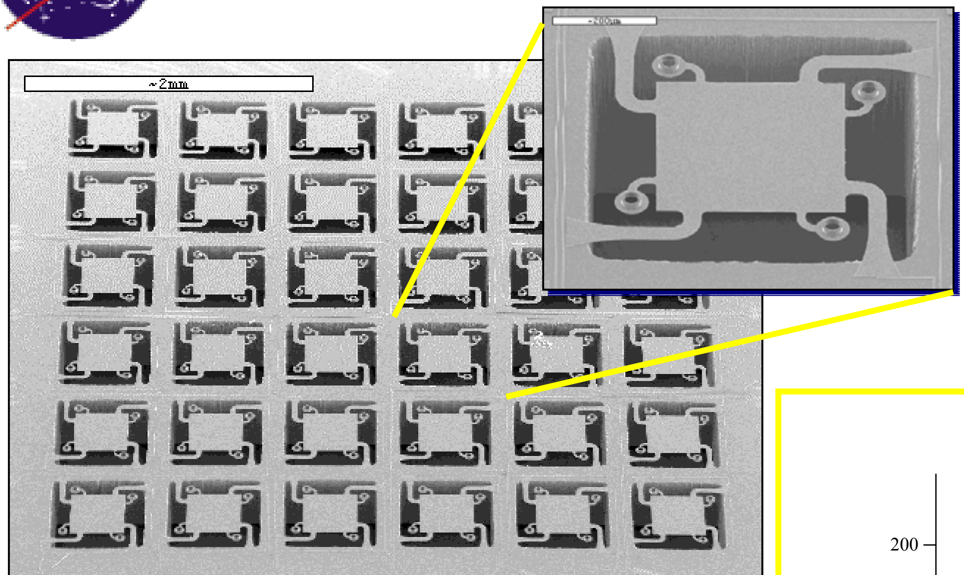
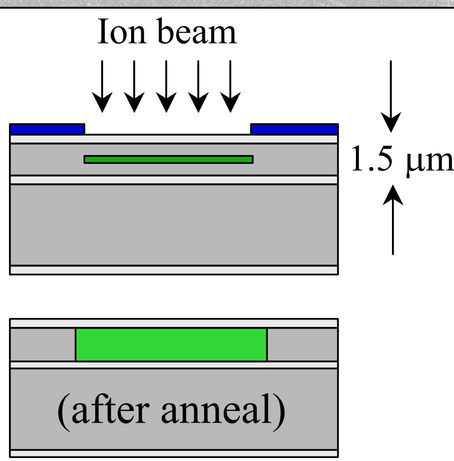
# New Micro-calorimeter Array for Astro-E2

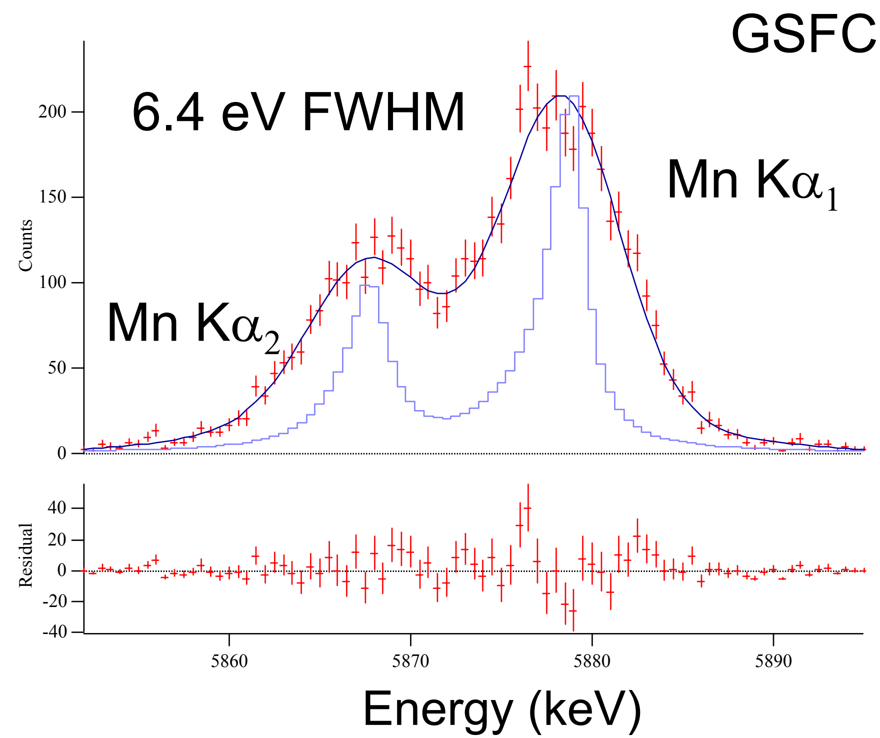



Deep implants using silicon-on-insulator wafers.

625 μm pixels




~ 6 times deeper thermometer

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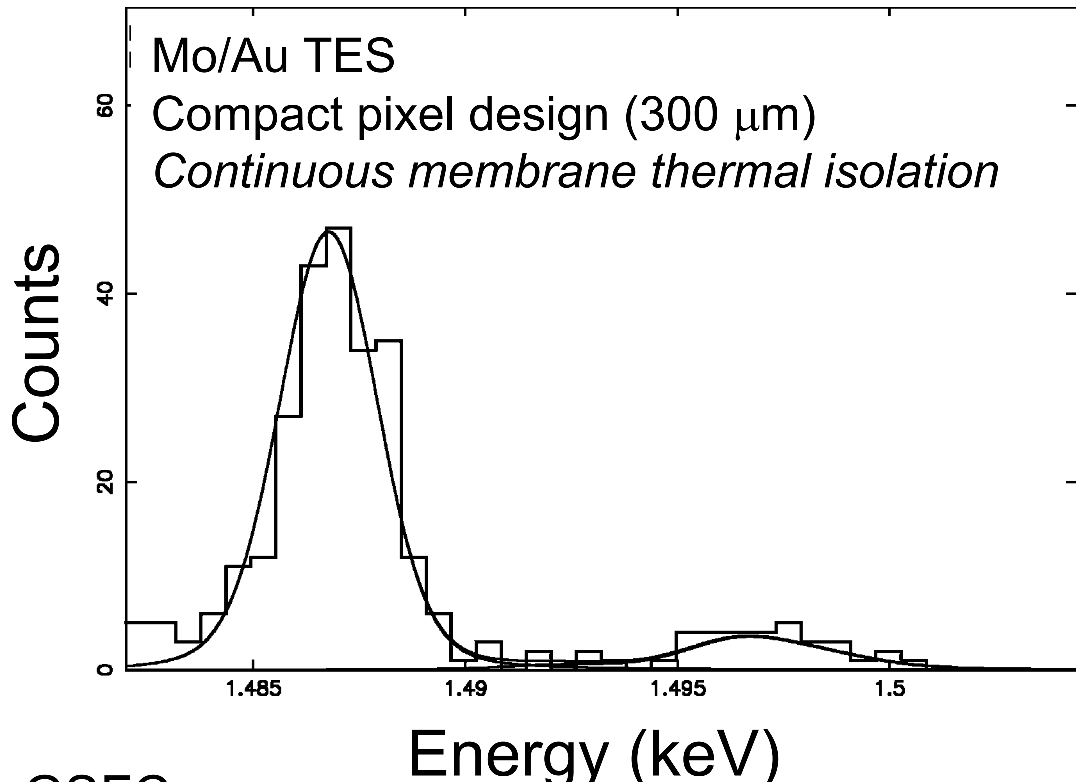
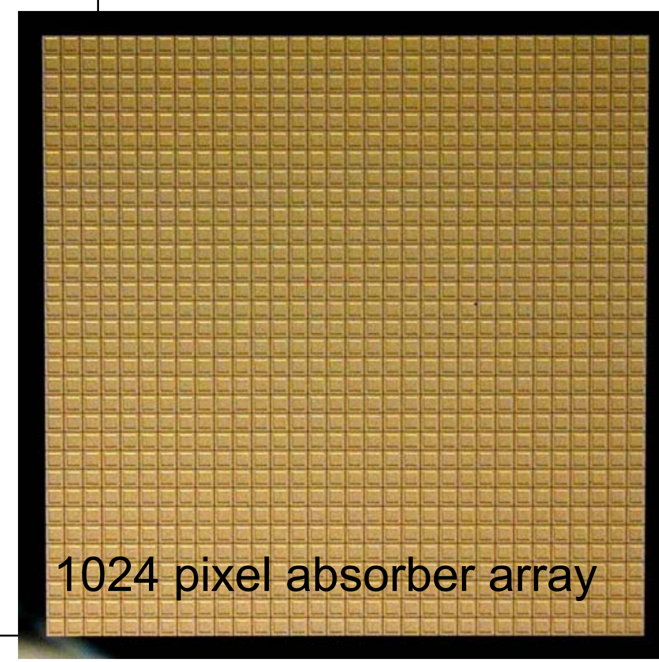
# Results from Compact TES Pixels

Energy Resolution = 2.5 eV (FWHM)




GSFC

*Paves the way for faster, more robust pixels for the Constellation-X Mission.*

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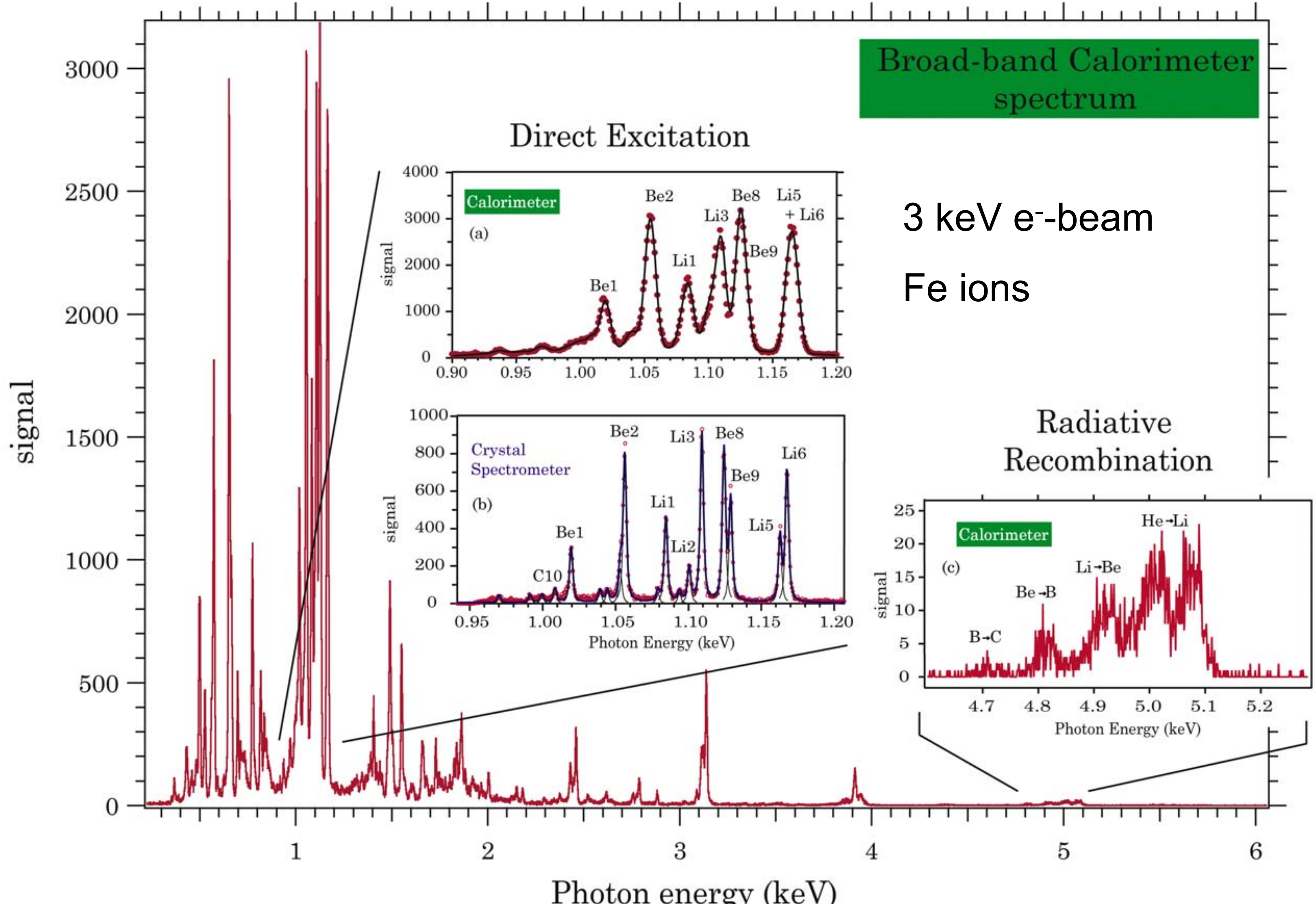
# XRS Microcalorimeter/EBIT Spectroscopy




3 keV e⁻-beam

Fe ions

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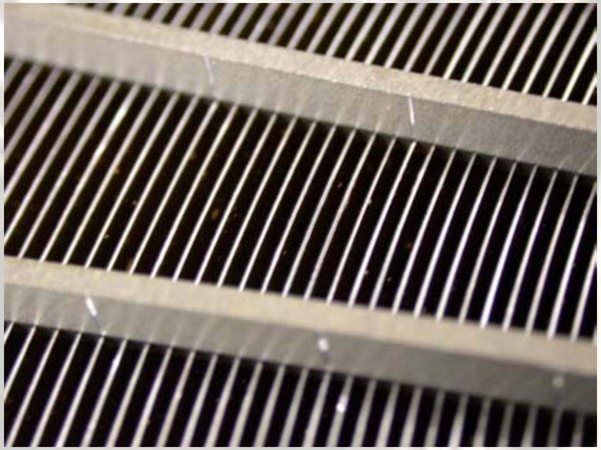
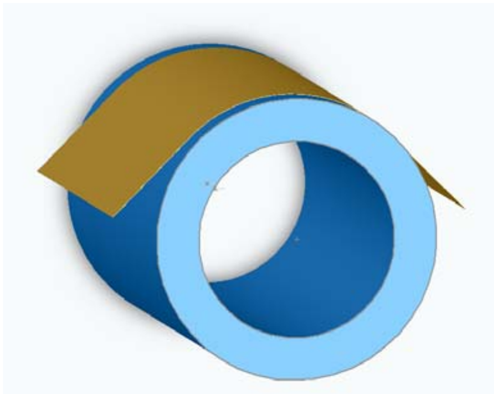
# Light-weight X-Ray Optics

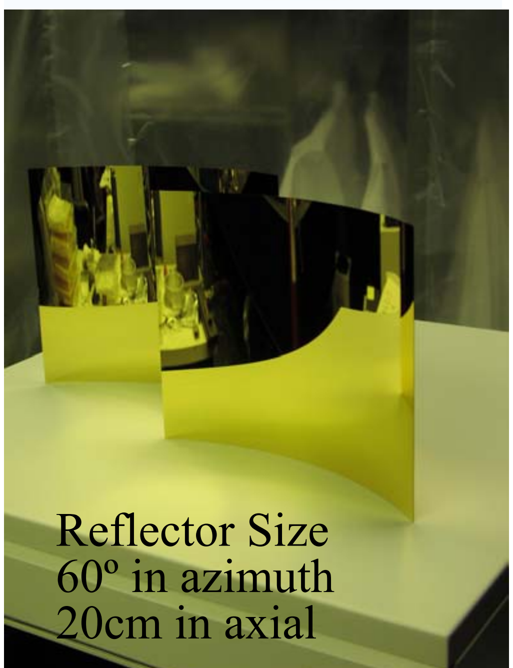
- Technology
  - Segmented, lightweight approach
  - Thermo-form aluminum foil substrate
  - Surface replication from smooth glass mandrels
  - Mono- or multi-layer coatings
- Heritage
  - BBXRT, ASCA, Astro-E & Astro-E2



- Future Developments
  - Thicker (300 μm) substrate for better axial figure
  - Improved replication mandrels
  - New scheme for precision alignment (1 μm) & stability

# Constellation-X Optics Development






**Substrate Forming**

- 0.4mm glass sheets thermally formed into precise substrate: good low order figure, but with high spatial frequency figure errors

**Epoxy Replication**

- Epoxy replication to eliminate high spatial frequency figure errors while preserving the low order figure of the substrate

**Current Status**

- Consistently achieving better than 20″ (2-reflection image HPD) level

**Goal**

- 10″ in one year and 5″ in 2 to 3 years

GSFC, SAO, MSFC, Columbia

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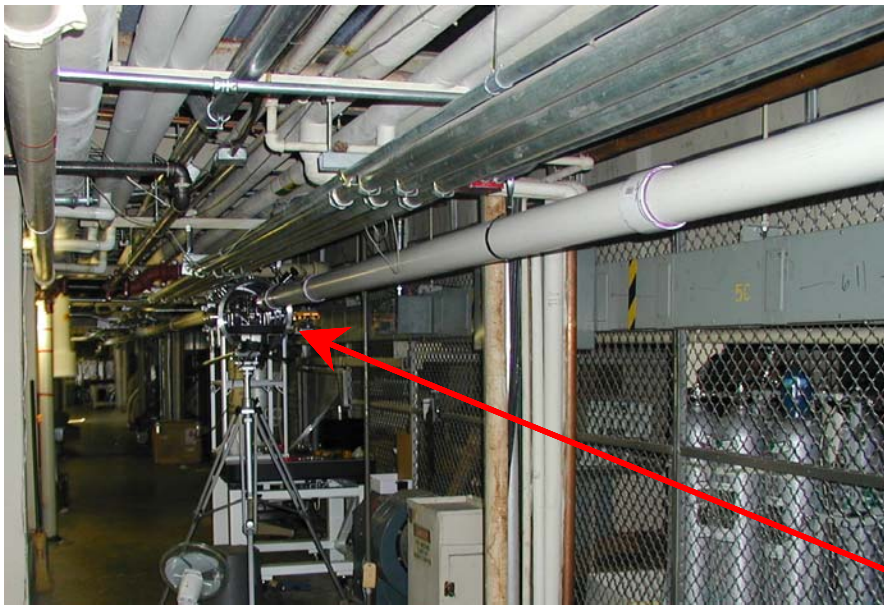
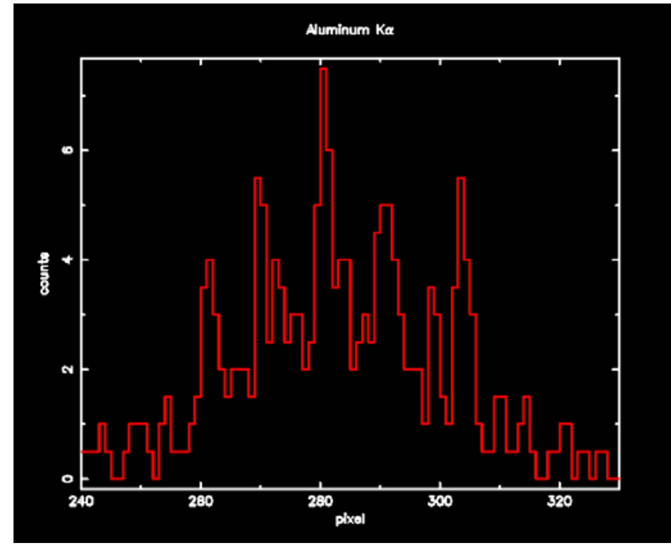
# GSFC X-ray Interferometer Testbed



Fringes at 8.35 Angstroms




80 m long X-ray beam line

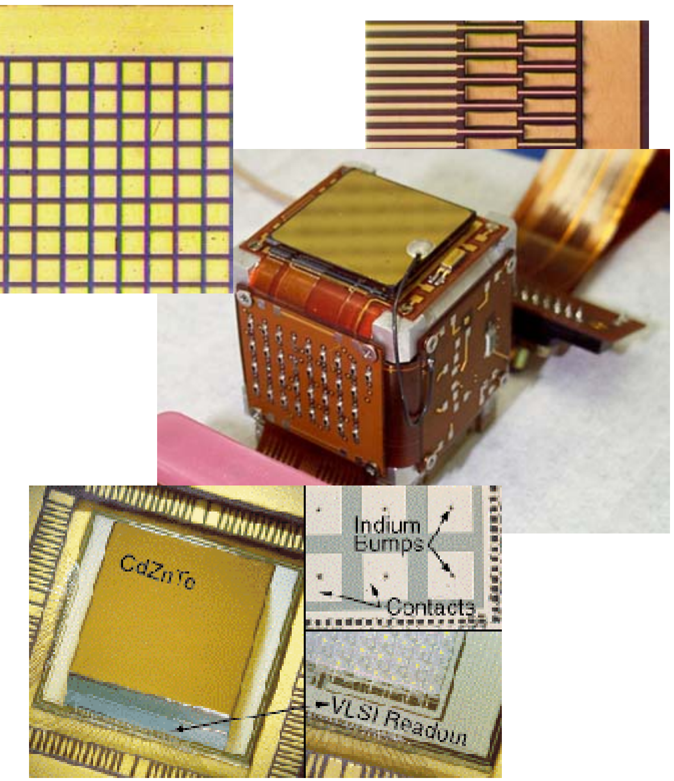
$\lambda/100$ rms flat optics collect x-rays over 1 mm baseline and combine onto X-ray CCD detector

Tests basic concepts for on orbit observatory

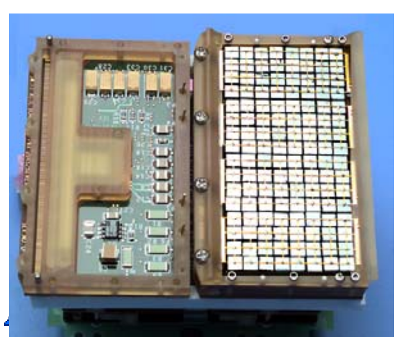
LHEA Laboratory for High Energy Astrophysics

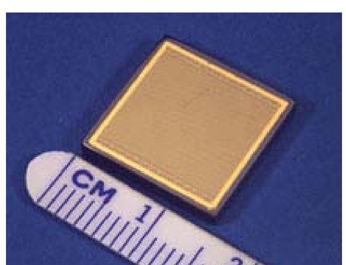
GSFC, University of Colorado

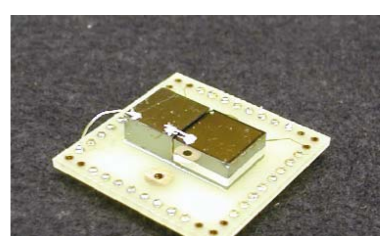
# *15 year Program of CdZnTe Detector Development at GSFC*

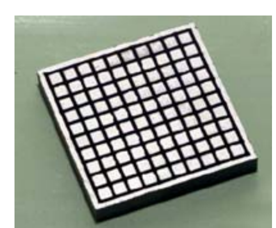



- Collaboration between GSFC Gamma-Ray and Detector Engineering branches
- Applications include Swift/BAT and InFOCμS balloon program
- Current research in areas of detector pixellization and packaging
- Collaborations with Harvard and Caltech
- Future applications include:
  - EXIST /Black Hole finder
  - Constellation-X/HXT







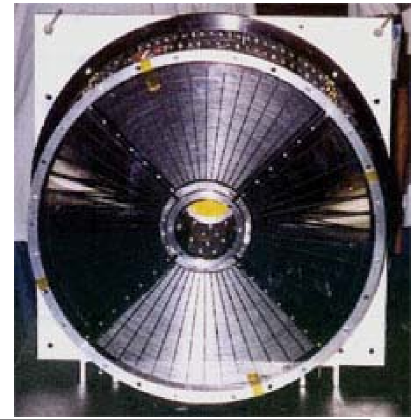
# InFOCμS Balloon Payload

## SCIENCE

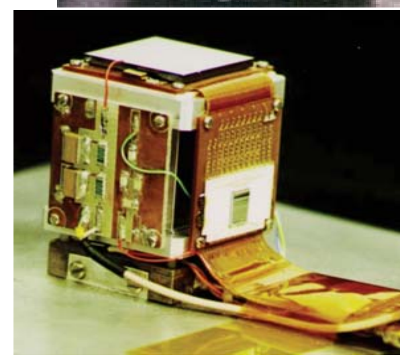
- Mapping $^{44}Ti$ nucleosynthesis and particle acceleration in young SN remnants
- Determine the origin of hard x-ray emission from clusters by imaging

## TECHNOLOGY

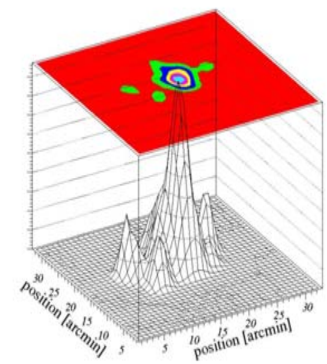
- Ultra low background CdZnTe focal plane using depth sensing and active shielding (~0.1 cnts/hr)
- Hard X-ray multilayer focusing optics 38 $cm^2$ at 30 keV



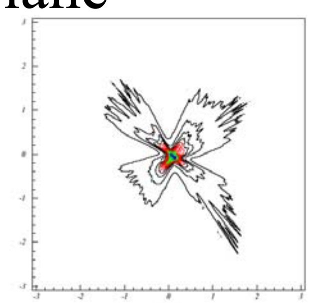
Multilayer mirror



focal plane




Cyg X-1



PSF

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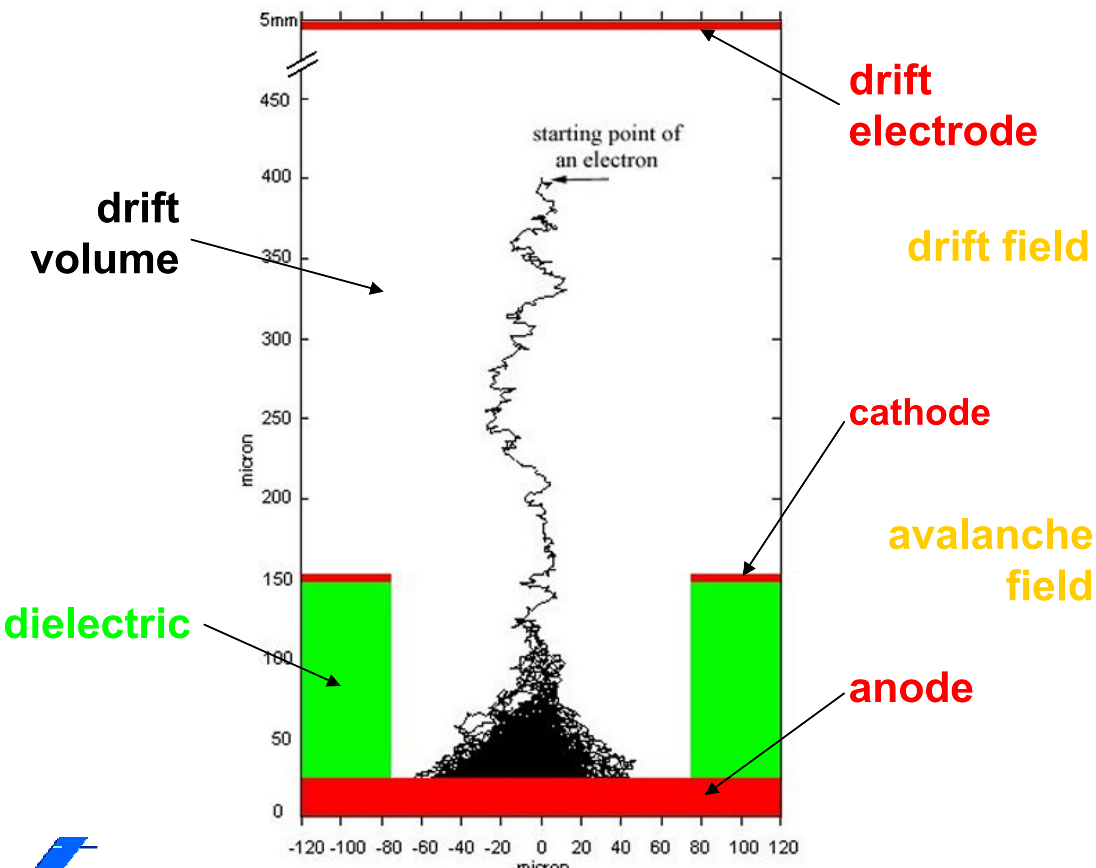
GSFC and Nagoya University

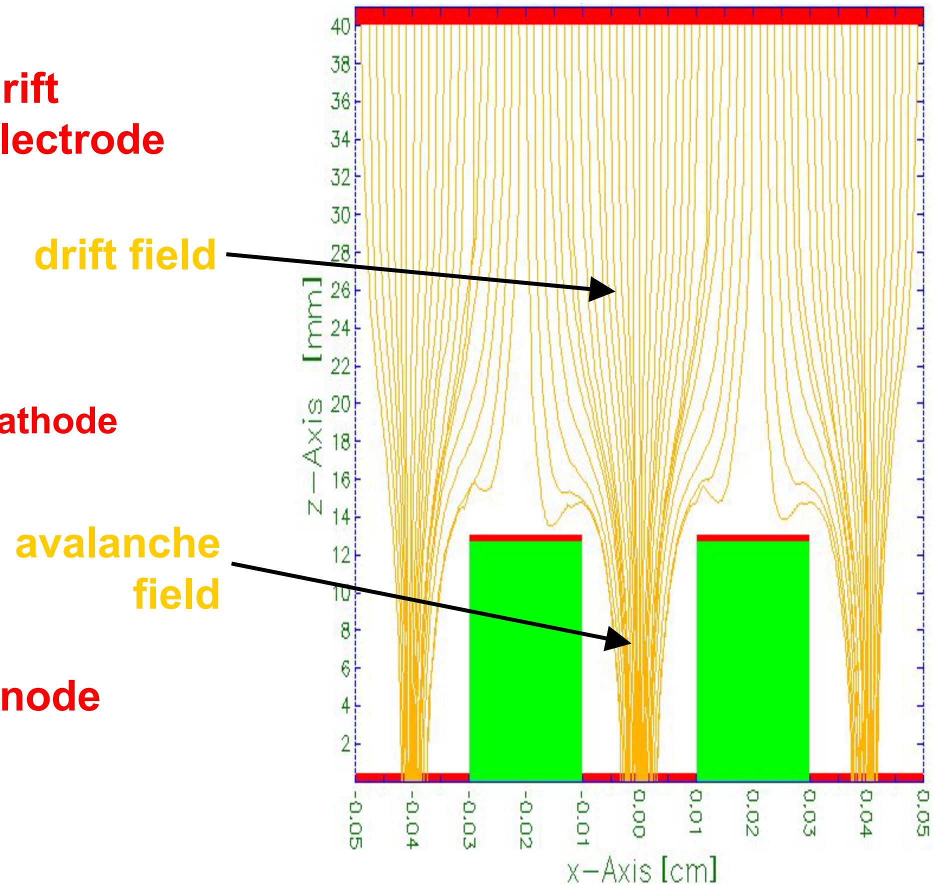
# Gas Micro-Well Detector

A pixelized gas proportional counter based on narrow-gap electrodes (also called the WELL or CAT)

Cross-section of a micro-well pixel with a simulated avalanche




An array of micro-wells focuses ionization electrons onto the anodes

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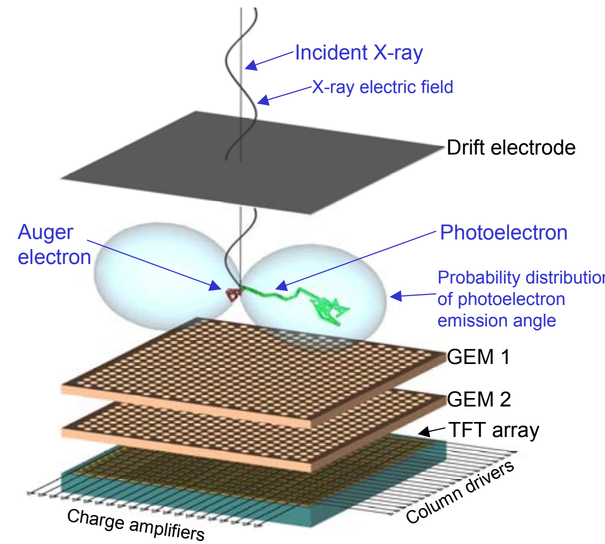
# Gas Electron Multiplier Application: Photo-electric X-ray polarimeter

Polarization key: Initial photo-electron direction is related to photon polarization

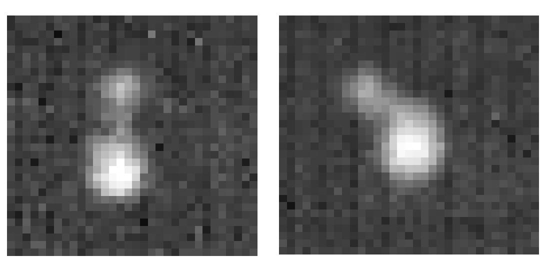
Measurement requirement: pixel imaging detector with pitch << track length

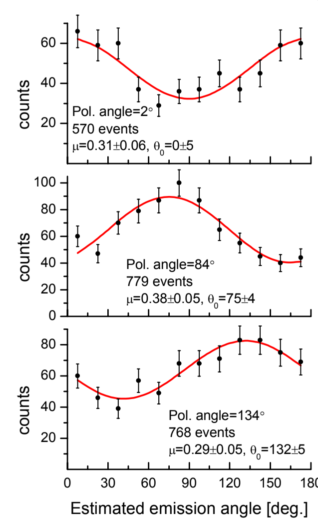
LHEA/PARC accomplishment: first photo-electron track images with active matrix (Thin Film Transistor array) readout.

Technology increases polarization sensitivity by orders of magnitude per collecting area, and will allow sensitive polarization measurements on a Small Explorer.




Tracks of 6 keV photons






Modulation curves measured at 4.5 keV (Black et al. NIM A, in press physics/0303114)

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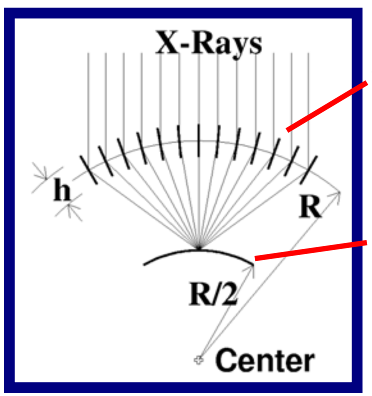
# Micro-Well Application: All Sky Monitor focal plane

Future all sky monitors using Channel Plate Optics (0.5-4 keV, 1 mCrab/day) requires focal planes with

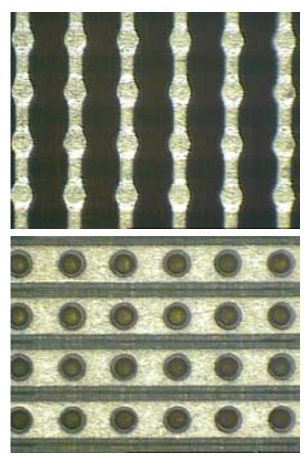
- Large Area: Six 400 $cm^2$ modules
  - achieved with four 10 cm panels/module
- Resolution: < 250$\mu$m matches MCP optics (~3')
- Approximately spherical: 37 cm radius
  - four panels mounted in pyramid maintain resolution

Lobster optics Geometry Cross section



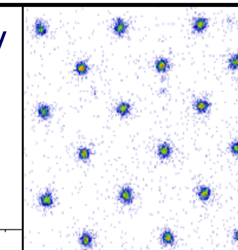

Black et al., NIM A in press, Physics/0305025

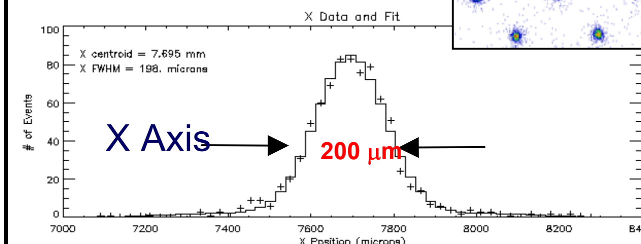
Anodes and Cathodes on 400$\mu$m pitch

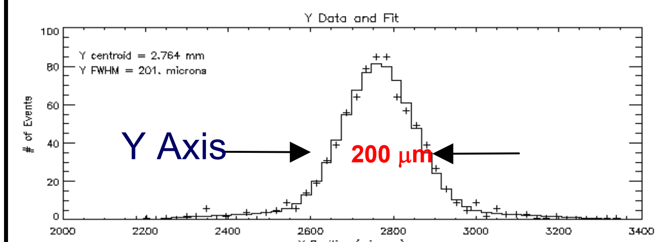


Microwell imaging performance

Image of shadow cast by 60 micron pinholes on a 2mm spacing (right).






Naturally imaging equal resolution in X and Y

Stable operation even at very high gas gains (~3 x $10^4$)

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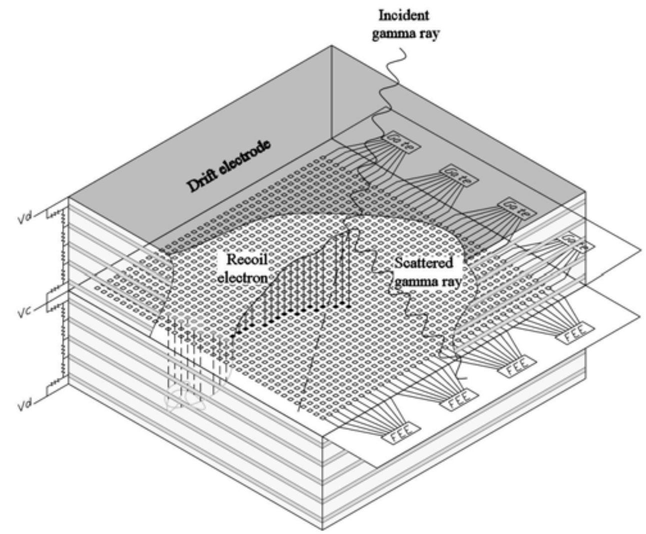
# Advanced Compton Telescope (ACT)

- ACT (0.5 - 50 MeV) science goals:
  - Study type Ia Supernovae and Galactic novae
  - Explore gamma-ray polarization
  - Image the Milky Way in nuclear lines ($^{26}$Al, $^{44}$Ti, $^{60}$Fe)
  - Study the MeV extra-galactic background
- ACT requires a low-density, charged particle tracker with moderate 3-D spatial resolution
  - A large xenon gas volume readout by pixelized micro-well detectors with thin-film transistor readout and ionization electron drift timing
  - Surrounded by CsI calorimeter
  - Goal to test prototype in ~3 years
- Advantage of this approach is **electron tracking with minimal scattering**
  - RMS error of 7° for 1 MeV recoil electrons in xenon at 3 atm
  - Electron tracking dramatically reduces PSF area for higher sensitivity, better imaging, and higher polarization sensitivity




One, double-sided 3-D micro-well track imager module of the *Advanced Compton Telescope* track imager

A NSWCCD/GSFC proposal to design and fabricate a Neutron Imager, using the ACT detector technology, is currently being reviewed by the Technical Support Working Group (TSWG). (*Neutron Imaging for Nuclear Material Detection*, N. Guardala, J. Price, & S. Hunter, Aug 2003)

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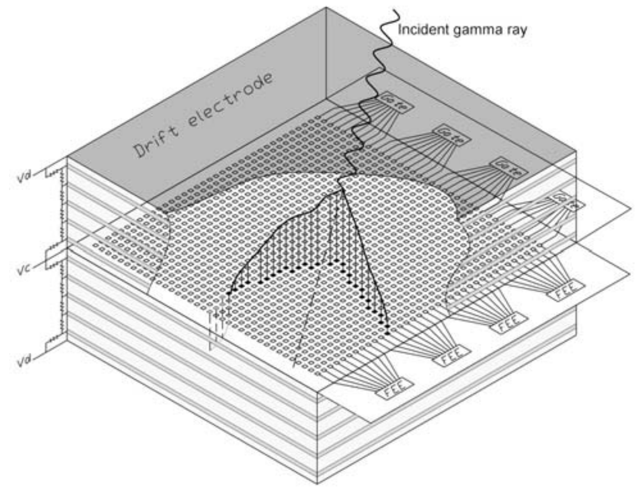
# Advanced Pair Telescope (APT)

- APT (30 MeV - 100 GeV) science goals:
  - Resolve the Milky Way gamma-ray emission into point sources and extended objects
  - Resolve the gamma-ray emission from local galaxies
  - Explore the polarized gamma-ray emission from strong sources
- APT requires a low-density, charged particle tracker with moderate 3-D spatial resolution
  - A large xenon gas volume readout by pixelized micro-well detectors with thin-film transistor readout and ionization electron drift timing
- Advantage of this approach is **electron tracking with minimal scattering**
  - Density less than $2 \times 10^{-5}$ RL/sample
  - RMS angular resolution < $1.5 \times$ nuclear recoil uncertainty limit up to several GeV
  - Sensitive to pair conversion on atomic electrons (triplet events)
  - Sensitive to gamma-ray polarization




One, double-sided 3-D micro-well track imager module of the *Advanced Pair Telescope* track imager

Collaborators: Penn State University, Dept. of Elec. Eng.

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# NIGHTGLOW

SCIENCE

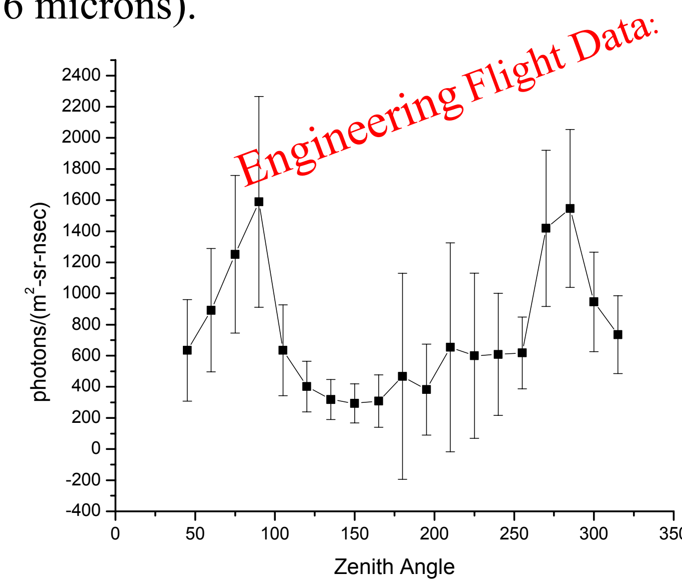
- Important background for UHE cosmic-ray airshowers, E above $10^{18}$ eV, observed w/fluorescence technique
- Needed for EUSO (and future OWL mission) design
- Measure the Near Ultra-Violet (300 – 400 nm) light produced in the upper atmosphere, from atomic oxygen and nitrogen, scattered starlight and artificial (man-made) lights
- Monitor the NUV light variations on spatial scales of 1 km and time scales of ~ 10 minutes

- Three Newtonian f/1.4 telescopes; 14" primary mirrors; two rotating; active LIDAR for correlated cloud cover observations; three IR bands (between 8 – 16 microns).

**GSFC**

**Univ. of Utah**

**New Mexico State University**




2003 – 2005: Balloon failure in January 2003 / Refurbish instrument and re-fly in Jan. 2005

Around the world flight attempt

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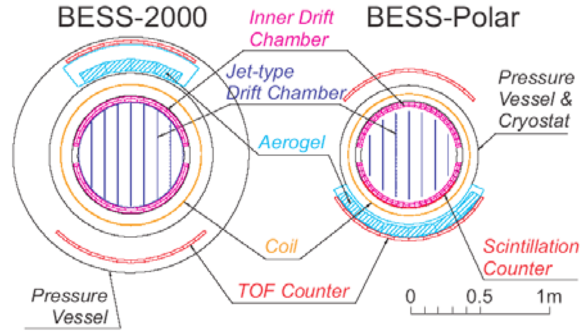
# BESS: Balloon-Borne Experiment with a Superconducting Spectrometer

KEK, GSFC, Univ. of Tokyo, Kobe Univ., ISAS, Univ. of Maryland




**Magnetic rigidity spectrometer** - 0.3 m$^2$sr AΩ, 200 GV MDR
solenoid, drift-chamber tracking, time-of-flight, aerogel Cherenkov.

**Nine balloon flights** since 1993. >2500 antiprotons recorded!

**Cosmic-ray particles and antiparticles** probe early Universe.

**ANTIPROTONS:** ***($\bar{p}/p \sim 10^{-5}$ @ 1 GeV)***

Mainly secondary: cosmic ray interactions with ISM.

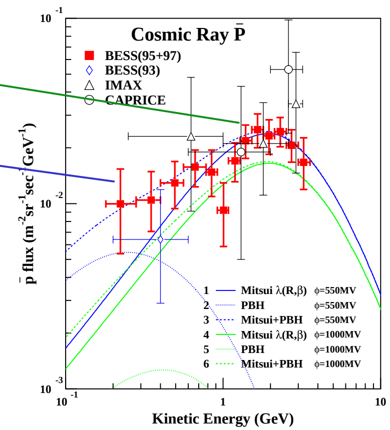
Possible small primary component;

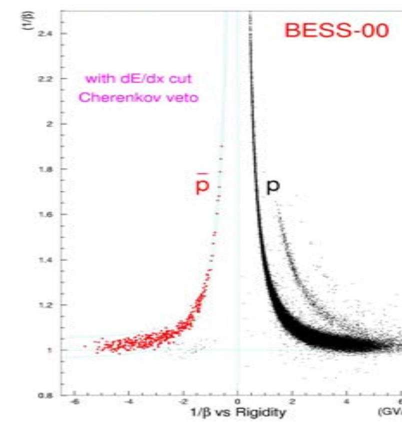
- Primordial black hole evaporation?
- Super-symmetric particle decay?

**ANTIHELIUM:** Probes symmetry of matter and antimatter.

Not observed in cosmic rays by any instrument!

BESS antihelium/helium limit 7 x $10^{-7}$ (through 2000).




BESS-Polar

## --- IN ADDITION ---

- Light element and isotope spectra.
- Proton and atmospheric muon spectra for interpretation of Super-K, SNO results.
- Charge-sign dependent Solar modulation.
- **New BESS-Polar for Antarctic flight**.
  - -Particle opacity 25% of BESS
  - -~100 MeV threshold.
  - -Single 20-day flight will >double present statistics.
  - -First flight Winter 2004-2005

BESS-2000

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# *Gravitational wave astrophysics activities*

- LISA R&D lab *(Stebbins, Camp, McNamara, Muller,Numata,Thorpe)*
  - measure structural stability of materials at picometer level
  - demonstration of LISA signal processing and extraction techniques,
  - laser stabilization studies, investigate iodine stabilized lasers for LISA
- LISA micro-Newton thruster characterisation *(Merkowitz)*
- LISA Instrument Modeling *(Merkowitz)*
  - "astrophysics to astrophysics" model of LISA before launch
- LIGO Scientific Collaboration *(Camp, Baker, Centrella, Strohmayer)*
  - instrumental characterization of the detectors
  - preparing to take part in the real data searches
- Source Modeling and Data Analysis *(Centrella, Baker, Brown, Choi, Fiske, Imbiriba, Van Meter)*
  - numerical relativity simulations of binary black holes
  - connecting source models to LISA integrated model….

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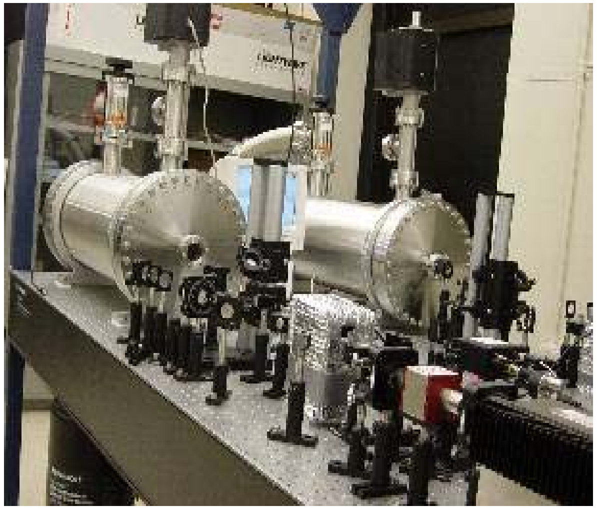
# Gravitational Wave Research at GSFC



- Frequency stabilized lasers for LISA and other NASA space interferometry missions
  - Optical cavity as frequency reference (LISA baseline)
  - Iodine molecular transition as frequency reference also being studied (supported by NASA SR&T grant)

- Development of ground testing methods for LISA and other interferometry missions
  - Active low frequency seismic isolation for testing of interferometry
  - Fused silica fiber development for advanced torsion pendulum, for testing of ultra-low acceleration noise (supported by GSFC DDF grant)

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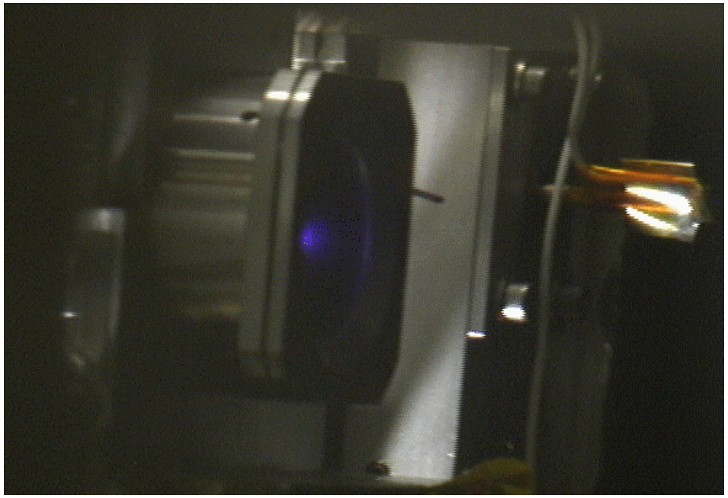
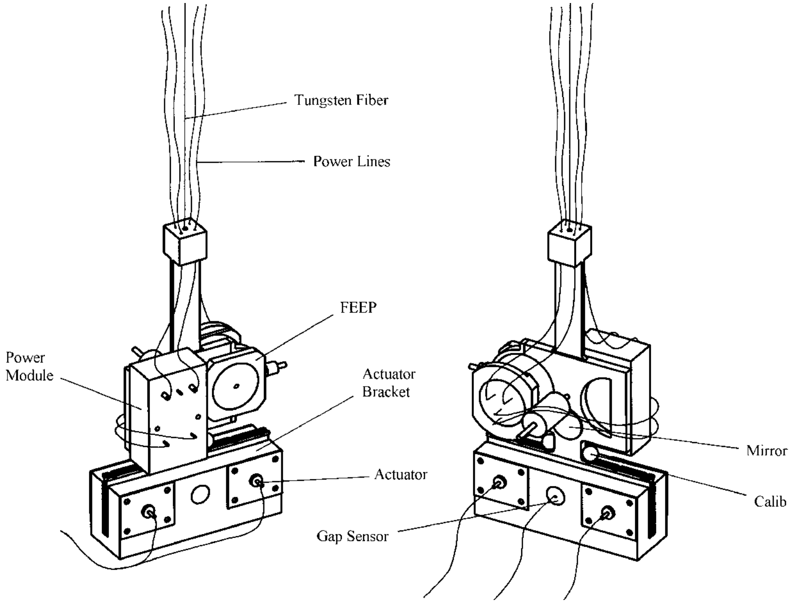
# LISA Micronewton Thrust-Stand

- Thrust-stand developed to test FEEP thrusters to LISA requirements:
  - Absolute thrust from 0-100 μN with 0.1 μN resolution
  - Thrust noise to 0.1 μN/√Hz from 0.1 mHz - 0.1 Hz
- Uses a torsion pendulum and techniques adapted from precision gravity experiments.






Laboratory for High Energy Astrophysics

# 2 Million Seconds of Chandra

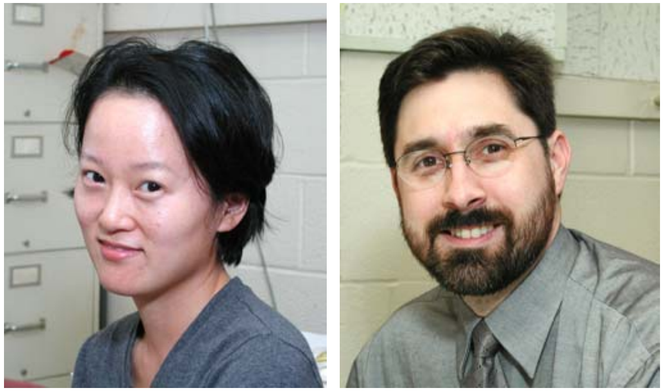
* Una Hwang (UMD, 662) and Kip Kuntz (UMBC, 662) have each won a mega-second of Chandra X-ray Observatory viewing time in the upcoming Cycle 5 "Large and Very Large Projects."

* Hwang's study is "*The Cassiopeia A Explosion: Getting at the Core Issues*."

-- Viewing time of Cassiopeia A will be 20 times greater than in any previous observation; study aims to understand core-collapse and nucleosynthesis in the supernova that produced Cas A.

* Kuntz's study is "An Ultra-Deep Study of M101."

-- A ten times greater exposure than previous observations should detect the majority of low-and high-mass X-ray binaries in spiral galaxy M101, a feat achieved so far only in the Andromeda and Milky Way systems; also will detect and resolve as never before extended sources such as supernova remnants and super-bubbles.



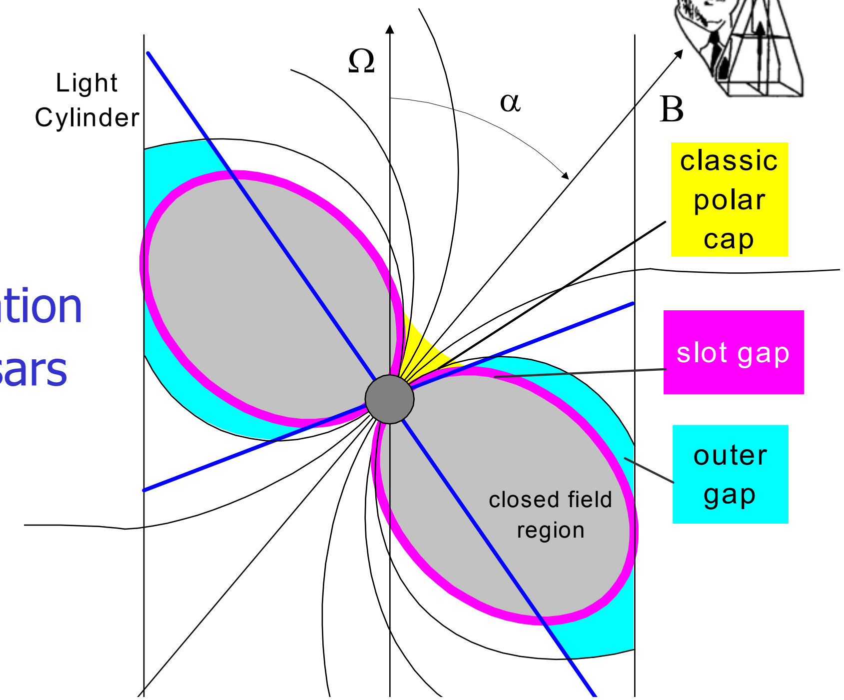
Una Hwang and Kip Kuntz

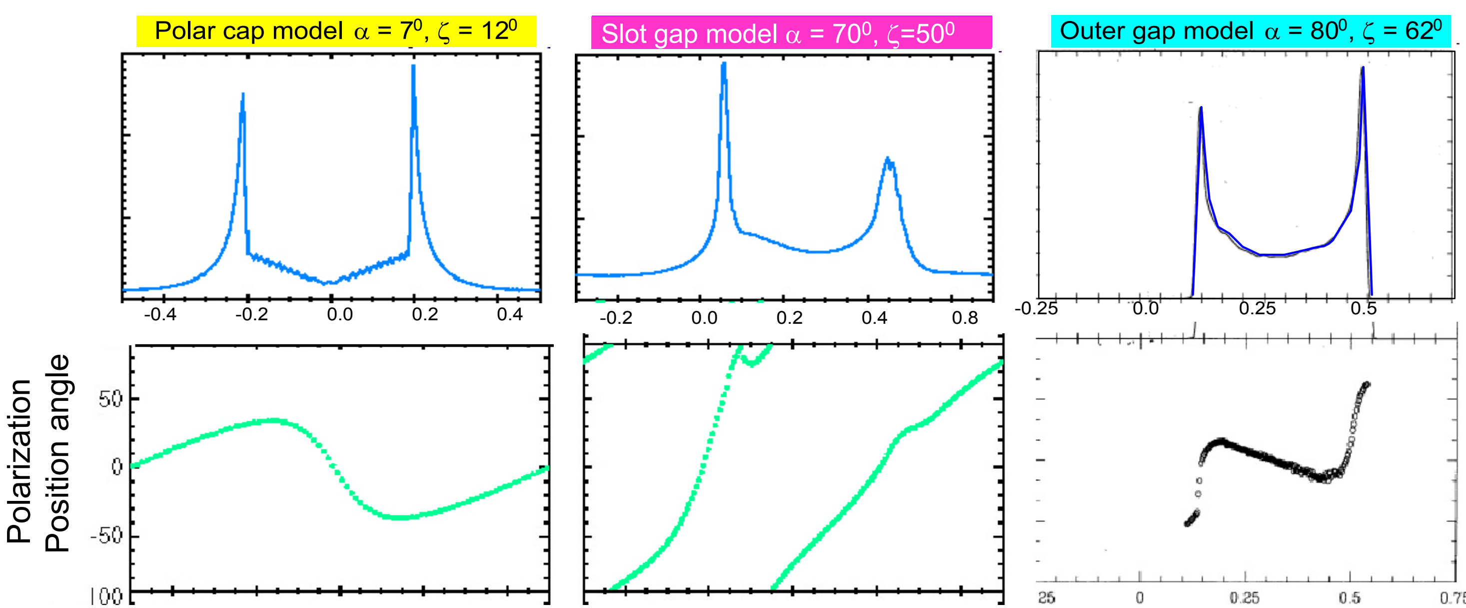
LHEA
Laboratory for
High Energy Astrophysics

# High Energy Emission from Pulsars

Alice Harding

- New developments in polar cap models
  - Particle acceleration in 'slot gap'
  - High energy emission at large altitudes
  - Polarization patterns of high energy radiation
  - Population studies of radio and $\gamma$-ray pulsars
- Predictions for pulsar observations with
  - X-ray telescopes (Chandra, XMM, Con-X)
  - Gamma-ray telescopes (AGILE, GLAST)
  - X-ray polarimeters (POGO, AXP)



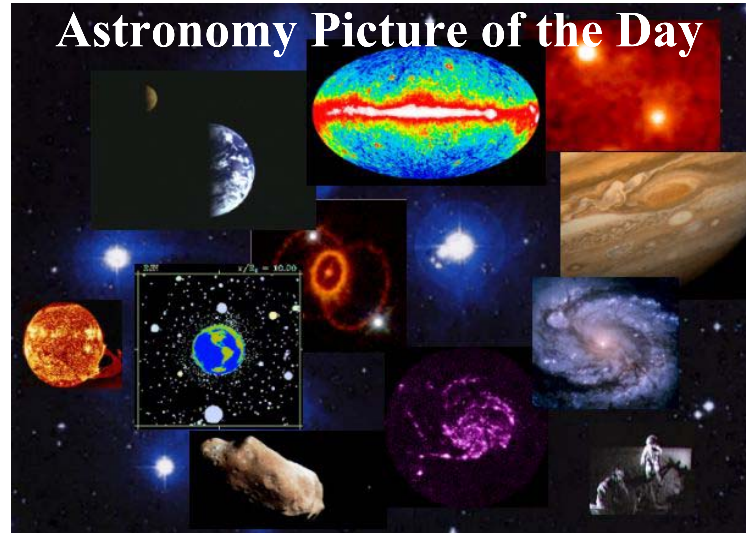

3 models…

Similar pulse profiles

Different polarization characteristics

# Education & Public Outreach

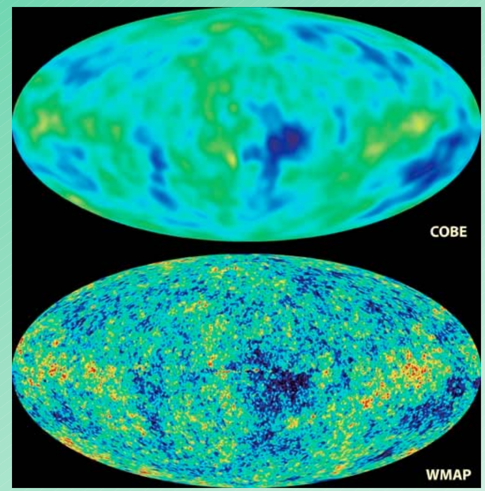
- Astronomy Picture of the Day Web site
- Imagine the Universe! Web site
  - Multi-level discussion of astronomy
  - Created by LHEA scientists & programmers collaborating with teachers
  - Lesson plans using actual satellite data
- Starchild Web site for K thru 14
- CD-ROM’s, posters, lesson plans
- Teacher conference support and workshops
- Ask A High Energy Astronomer service

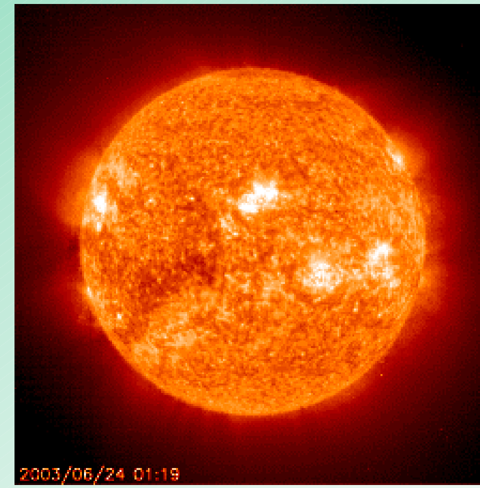





LHEA
Laboratory for
High Energy Astrophysics

# Laboratory for Astronomy & Solar Physics (LASP)




UV/Optical Astronomy Branch (HST, JWST, TPF)

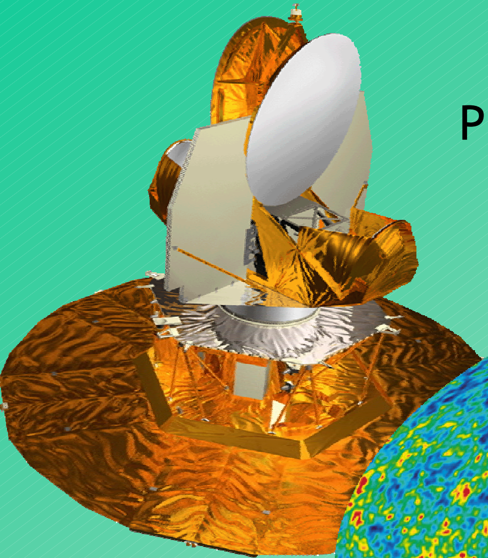
IR Astrophysics Branch (WMAP, JWST, SOFIA, TPF)

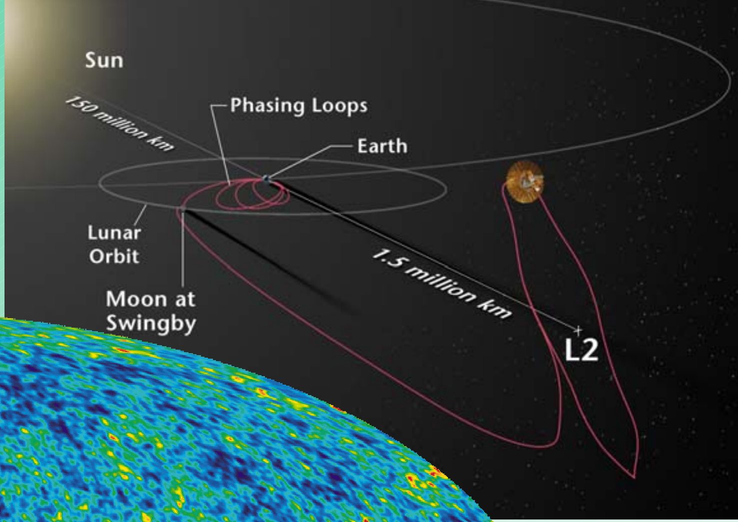
Solar Physics Branch (RHESSI, SOHO, SDO)

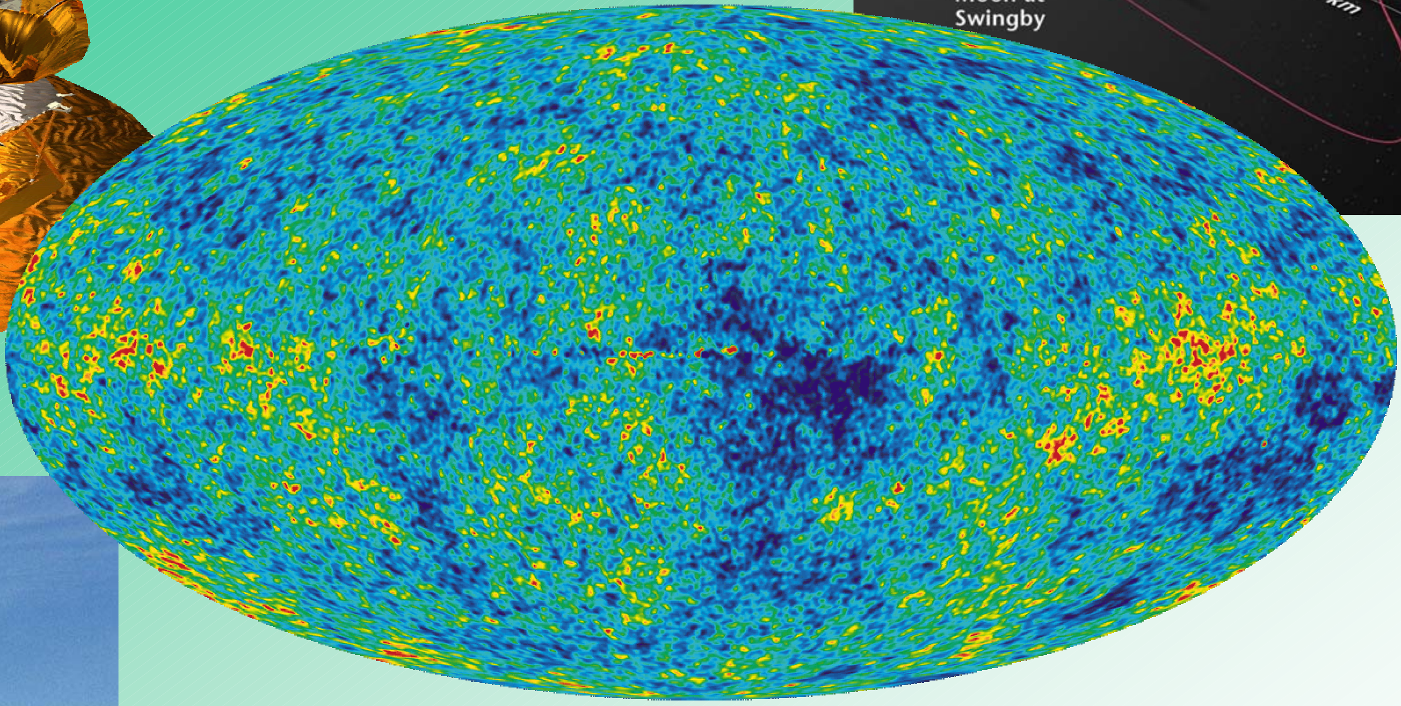
Supporting SEU, Origins and SEC themes

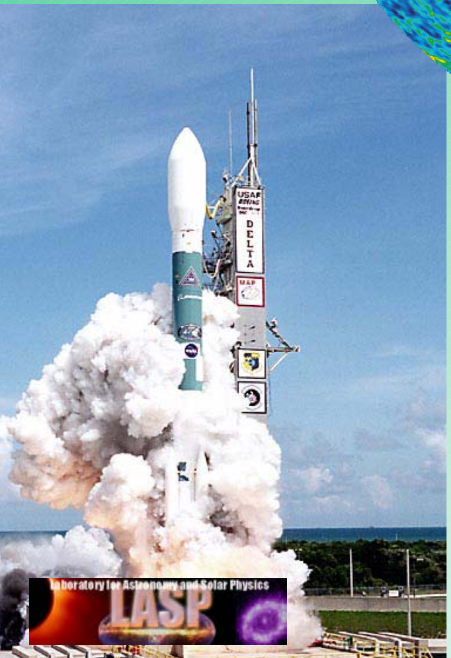
# Wilkinson Microwave Anisotropy Probe (WMAP)

PI: C. Bennett (GSFC)








Discovered era of first stars (200 million years after Big Bang)

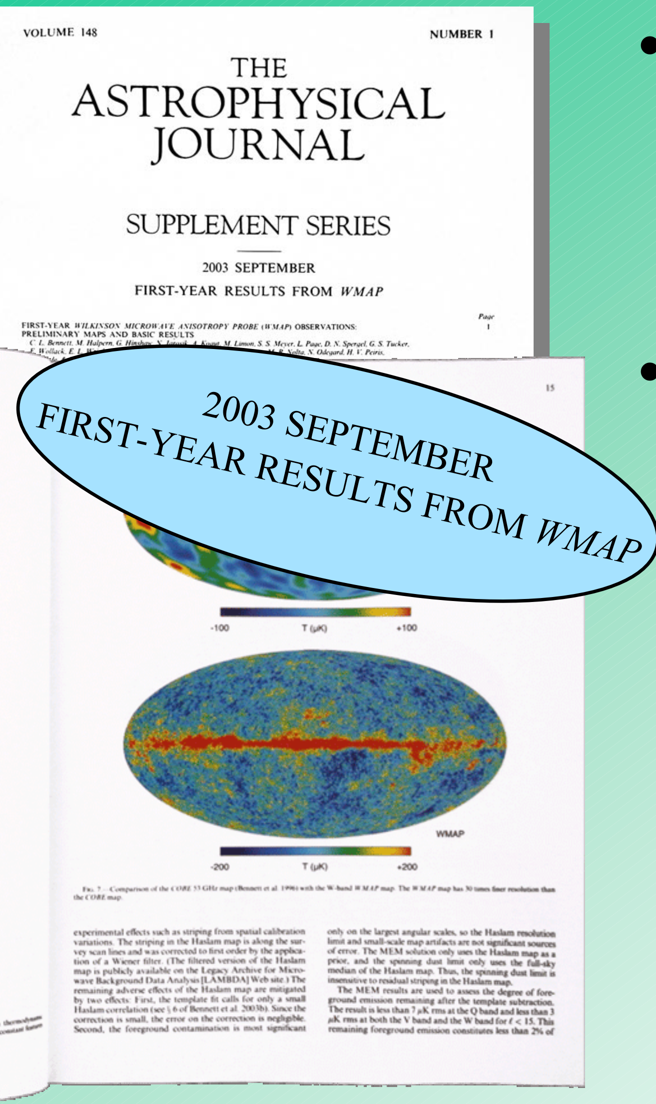
Cosmological numbers:

- Age of universe = 13.7 billion years old
- Content of universe: 73% dark energy, 23% cold dark matter, 4% atoms
- Equation of state of dark energy $w = -0.98 \pm 0.12$

Support for Inflation theory, but some specific versions are ruled out

4 years of observations approved - 2 years of observations completed

# WMAP Papers and Data Public


VOLUME 148 NUMBER 1

THE ASTROPHYSICAL JOURNAL

SUPPLEMENT SERIES

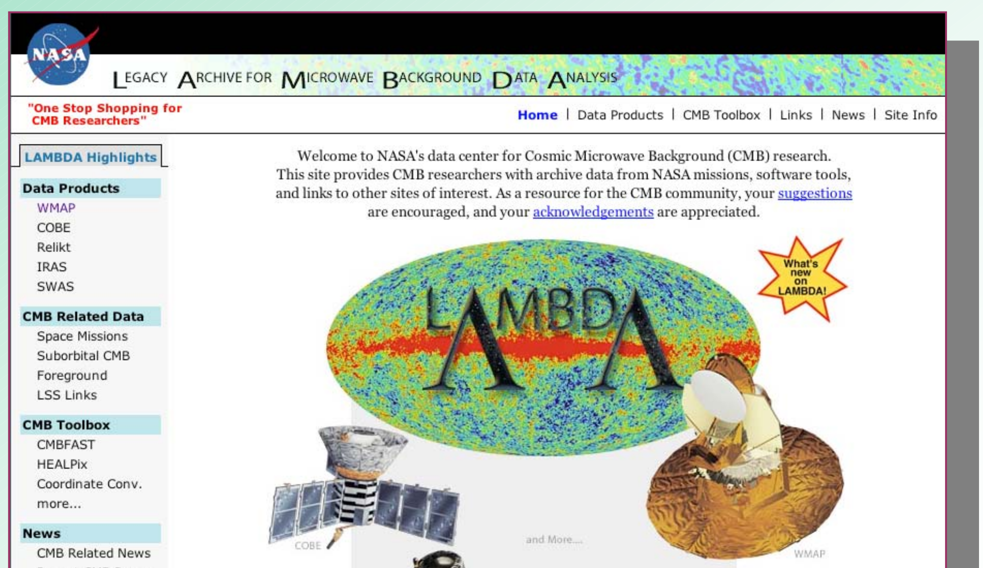
2003 SEPTEMBER

FIRST-YEAR RESULTS FROM *WMAP*

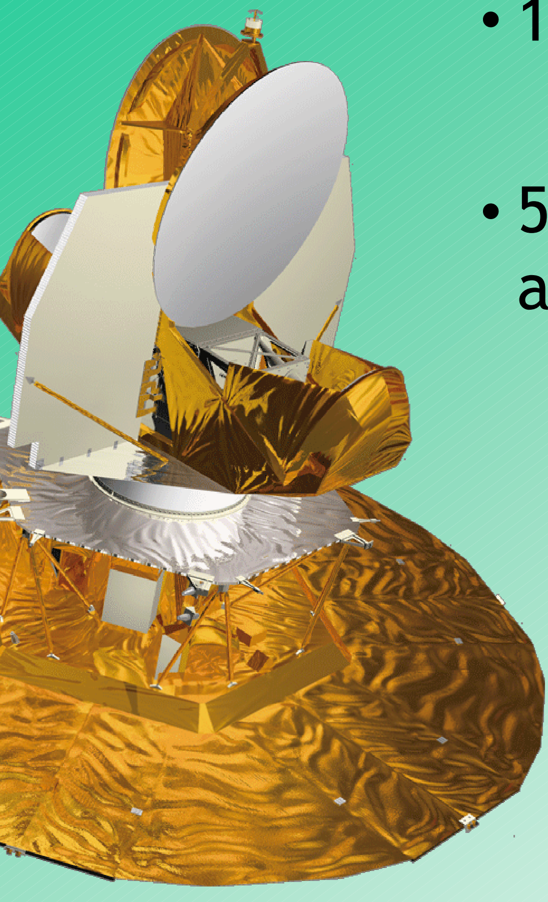


- WMAP TEAM PAPERS
  13 papers by WMAP Team in dedicated issue of the Astrophysical Journal Supplement Series, September 2003

- WMAP DATA ONLINE
  NASA data center run by LASP Legacy Archive for Microwave Background Data Analysis (LAMBDA)



# Science Community Digs into WMAP Data

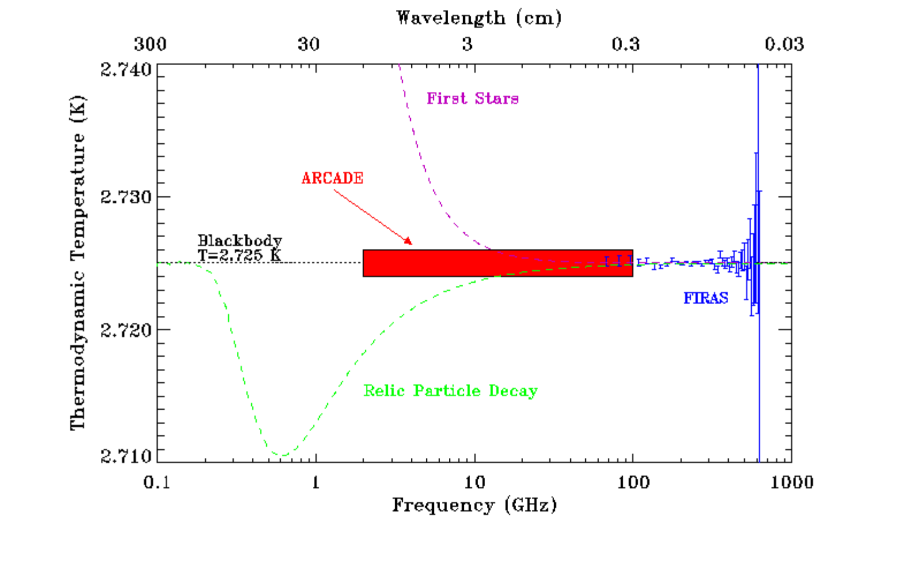


- 1st outside paper using WMAP data appeared only 36 hours after its release
- 500+ new papers based on WMAP have appeared since the data release.

  Topics include:
  - Early ignition of the first stars in the universe
  - Limits on the mass of the neutrino
  - Limits on the mass of the lightest super-symmetric particle as the dark matter
  - Re-examination of the Big Bang production of the light elements
  - New limits on the nature of the dark energy
  - Important clues about the nature of the first moments of the universe ("Inflation Theory")
  - Correlations of WMAP maps with other structure maps, probing the dark energy
  - Very low signal on angular scales $>60^\circ$
    - ➢Hint of new fundamental physics?
    - ➢Finite universe?
    - ➢Closed universe?

# ARCADE: Absolute Radiometers for Cosmology, Astrophysics, and Diffuse Emission

## *A New View of the First Light*




GSFC-JPL-UCSB Collaboration High-altitude balloon payload Prototype for DIMES space mission

To eliminate corrections from warm objects in the beam, ARCADE uses open-aperture cryogenic optics at the mouth of a large bucket dewar, with no windows between the 2 K optics and the atmosphere.

Observations of deviations from CMB caused by free-free emission from the First Stars at z 10-20

- End of the cosmic "Dark Ages"
- Beginning of "modern" universe

Boiloff helium gas from a superfluid LHe reservoir serves as a barrier to prevent condensation of solid nitrogen on the optics.

Successful Flights of 60 cm test optic in 2001 and 2003

Search For Relic Decay

- Dark Matter
- GUT Physics

Flight of 150 cm optic planned for 2005

# Ultraviolet Detector Program

B. Woodgate, R. Kimble

Tim  Norton standing next to vacuum tank in detector lab Building 21, LASP

**New photocathode materials are being tested for use in the UV (AlGaN, etc) to increase the QE by factors of 3-4.**

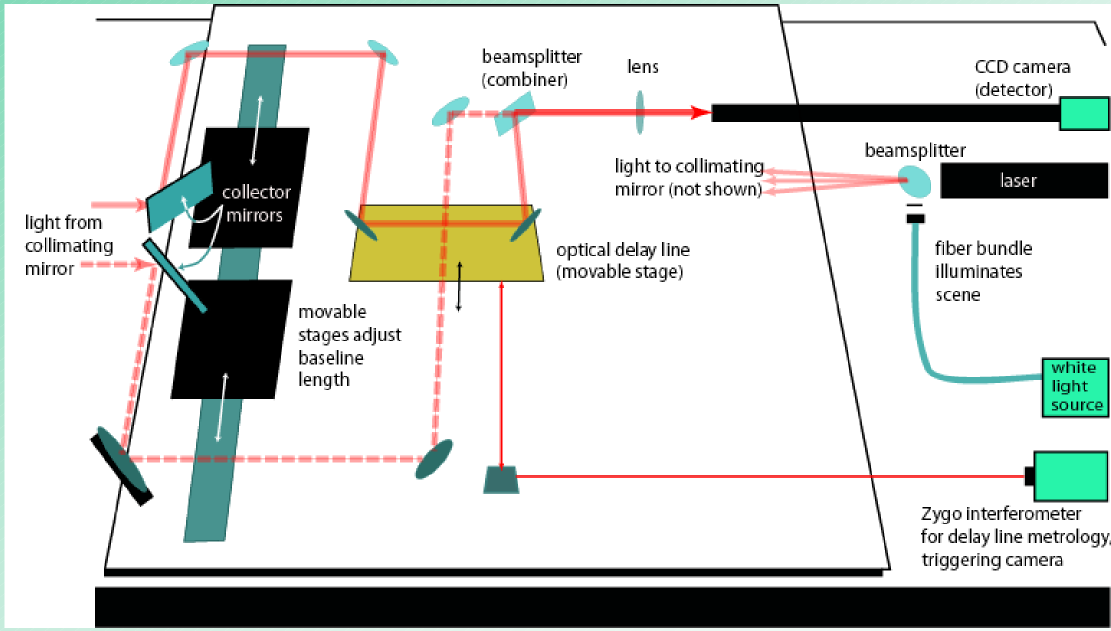
Photocathodes will be deposited on silicon microchannel plates to produce high QE, low background, photon-counting detectors.

The team is working with JPL to design, build and test event-driven **Active Pixel Sensor** (APS) devices, for a high performance readout system for MCP detectors.  This readout system offers high dynamic range, high spatial resolution, is compact and requires lower power than competing MCP readouts.

This work supports future Explorers and the next Large Aperture UVO telescope

**LASP supports a number of interferometery testbeds** for SEU, SEC, and Origins programs.

The goal of the **Wide Field Imaging Interferometry Testbed (WIIT)** is to demonstrate that an optical/IR Michelson stellar interferometer with a multi-pixel detector array can image a complex, *extended* scene over a wide field of view ($>> \lambda / D_{tel}$ , where $D_{tel}$ is the diameter of the aperture of an individual interferometer array element).

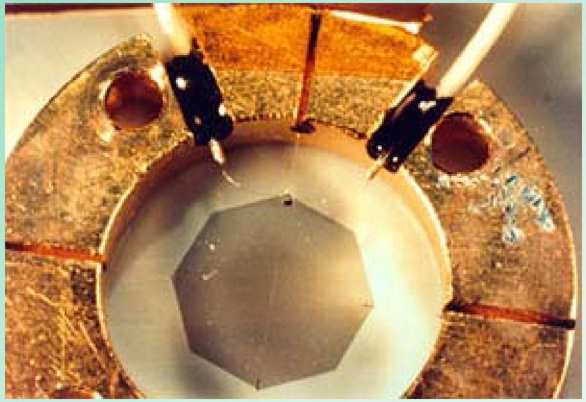



WIIT is a scale-model for SPECS (Sub-mm Probe of the Evolution of Cosmic Structure), a formation-flying interferometer designed for high spatial resolution imaging in the far-IR (Leisawitz).

# GSFC Far-IR Detector Development

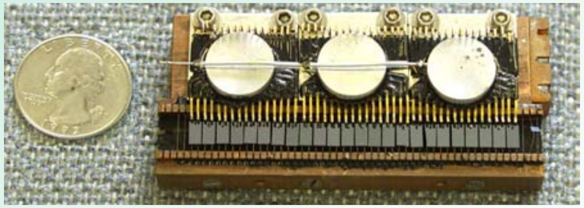
COBE

GSFC bolometers measured CMB spectrum & detected cosmic far-IR background



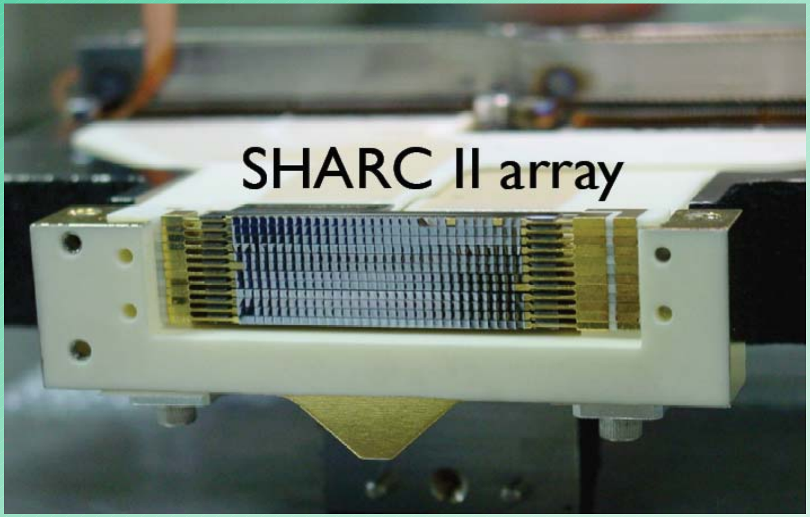
KAO

GSFC bolometers measured SN1987A spectrum (first far-IR supernova spectrum) using 24 element spectrometer array

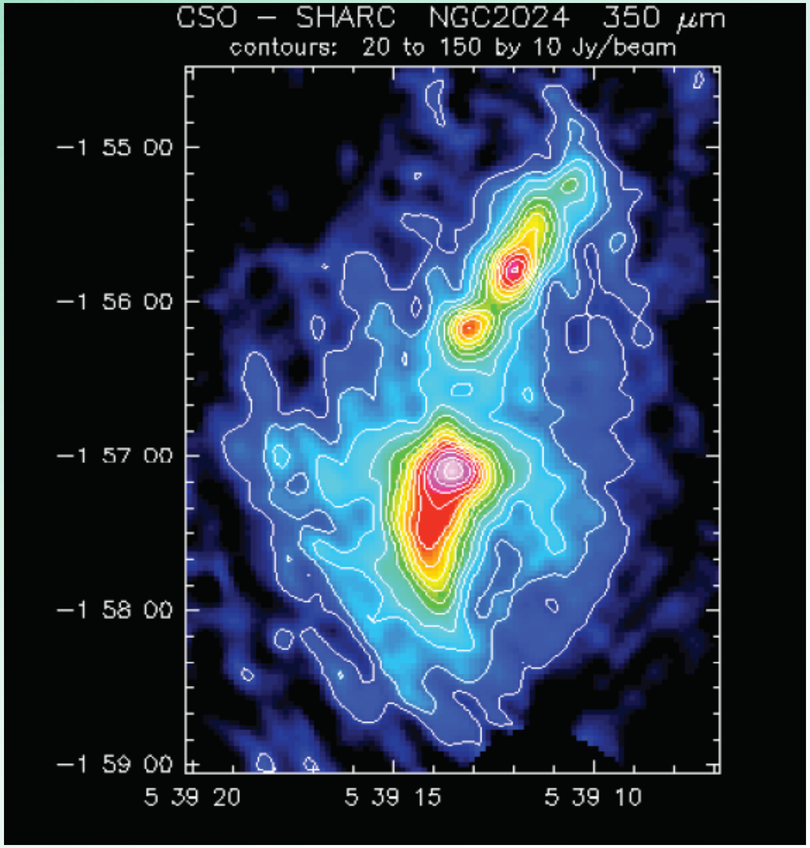


# GSFC Far-IR Detector Development

The SHARC II array at CSO is the largest cryogenic bolometer array in operation today: proto-type for the SOFIA HAWC,




*SOFIA*
*HAWC (SHARC-II) Array*
*$\lambda$=50-200μm (350μm)*
*384 elements*
*2002*



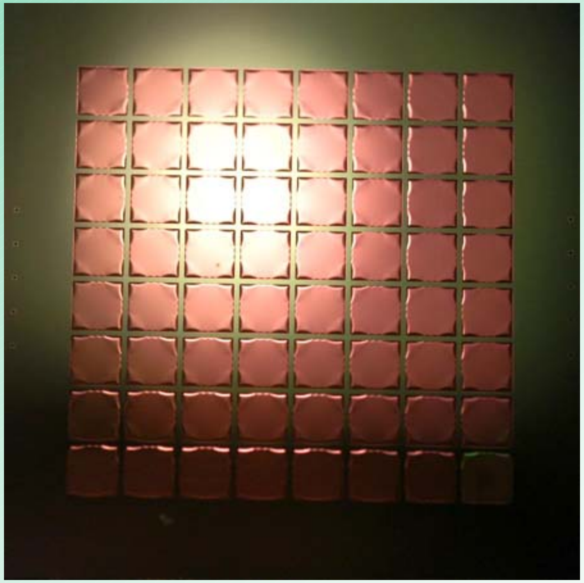
# Future Long Wavelength Sensors

<u>**NASA Requires :**</u>

**Detectors for the Einstein Inflation Probe**
- ***Very sensitive (NEP~$10^{-18}$ W/√Hz)***
- ***λ=500-3000μm***
- ***~$10^4$ elements***

**Detectors for SAFIR and SPECS:**
- ***Extremely sensitive (NEP~$10^{-19}$-$10^{-20}$ W/√Hz)***
- ***λ=20-800μm***
- ***~$10^4$ elements***

Superconducting transition edge sensor (TES) bolometers and microcalorimeters are a promising technology for meeting speed and sensitivity requirements for:
  X-ray energy resolving spectrometers (e.g. Con-X)
  Einstein Inflation Probe (CMBPOL)
  Far-IR imagers and spectrometers (e.g., SAFIR, SPECS)
GSFC is doing leading edge research & development for these applications



**GSFC is developing detectors for these future missions, and many smaller projects along the way.**

***(a prototype planar 64-element TES bolometer array – developed by GSFC for the 100m Green Bank Telescope)***